

# Bounded Rationality as an Essential Component of the Holdup Problem<sup>1</sup>

by Mathias Erlei and Wiebke Roß<sup>2</sup>

Clausthal University of Technology

**Abstract:** We provide experimental evidence for the hypothesis that bounded rationality is an important element of the theory of the firm. We implement a simplified version of a mechanism designed to perfectly solve the holdup problem under conditions of perfect rationality (Maskin 2002). We test whether this mechanism is able to perfectly solve our experimental holdup problem or may at least improve economic performance. We find that this is not the case: the implementation of the mechanism worsens economic performance. We reconstruct the main features of participants' behavior by applying the logit agent quantal response equilibrium (McKelvey and Palfrey 1998) as an equilibrium concept that takes players' potential mistakes into account.

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<sup>2</sup> E-Mail addresses: [m.erlei@tu-clausthal.de](mailto:m.erlei@tu-clausthal.de) and [wiebke.ross@tu-clausthal.de](mailto:wiebke.ross@tu-clausthal.de).

## 1 Introduction

Bounded rationality is an important element of the theory of the firm and the theory of institutions in general. The objective of this paper is to provide experimental evidence to support the first of these statements. In our experiment we implement a simplified version of a mechanism designed to perfectly solve the holdup problem (Maskin and Tirole 1999, Maskin and Moore 1999 and Maskin 2002). We test whether this mechanism is able to perfectly solve our experimental holdup problem or at least improve economic performance. We show that neither is the case: the implementation of the mechanism worsens economic performance.

The theory of the firm has a long tradition. In the 1970s several contributions identified the holdup problem as one core element of the theory of the firm (Williamson 1975, 1985, Klein, Crawford and Alchian 1978 and Alchian 1984). This strand of literature is known as transaction cost economics. Corresponding empirical research has provided an impressive amount of findings confirming of the basic hypotheses (cf. Lafontaine and Slade 2007 and Shelanski and Klein 1995). Unfortunately, much of the prior transaction cost economics literature employed a verbal approach and hence the description of the interdependencies between the central variables remained rather vague. The use of methods changed substantially with the publication of the seminal paper by Grossman and Hart (1986) introducing the property rights model. As in transaction cost economics, the property rights approach places the holdup problem at the center of the analysis but employs game theoretic tools of analysis. In the years that followed an impressive number of game theoretical variations and refinements emerged, meaning that the former property rights model evolved into a much broader theory of incomplete contracts. Hart and Moore (1990) and Hart (1995) are essentially extensions of Grossman and Hart (1986). Rosenkranz and Schmitz (2003), Schmitz and Sliwka (2001) and Schmitz (2006) provide variations of the property rights model. In addition, a parallel strand of research emerged with the aim of solving the holdup problem using contractual solutions. Some of the most important of these papers are Hart and Moore (1988) and Edlin and Reichelstein (1996). Che and Hausch (1999) show that the proposed solutions to the holdup problem are based on the assumption of “selfish investments” and that in case of “cooperative investments” no contractual solution exists if players cannot commit not to renegotiate.

However, Maskin and Tirole (1999), Maskin and Moore and Maskin (2002) show that a mechanism exists that is able to solve the holdup problem perfectly, even in the case of cooperative investments. As a consequence, this mechanism questions the theoretical foundations of the entire theory of incomplete contracts: there is no longer a holdup problem because the first-best outcome can always be achieved provided that all players have perfect foresight. Although Maskin (2002) emphasizes that the heuristic value of the contributions to the theory of incomplete contracts remains unchanged, the interest in incomplete contract theory has decreased and some of its main contributors proposed aspects other than the incompleteness of contracts are central to the contracting problem;

e.g. Hart and Moore (2008, 2009) introduce a semi-behavioral theory of contracts and ownership.<sup>3</sup>

Parallel to the development of the theory of the firm, the role of bounded rationality has also changed. Initially (Williamson 1975, 1985) bounded rationality occupied a central position in the theory of the firm; subsequently, however, it essentially disappeared from the scene. As early as 1990, Oliver Hart claimed that bounded rationality is not a crucial component of the theory of institutions (Hart 1990, 696) and many economists followed his assessment by restricting their analysis to standard game theoretic equilibrium concepts. Yet Eric Maskin himself (2002, 732) supposes that the rather complicated mechanism he introduced may excessively rely on agents' abilities to foresee future payoffs.

We follow Maskin's supposition by implementing a special and substantially simplified version of his mechanism in our laboratory experiment. We organized the experiment such that the participants did not need to calculate parameters that make the mechanism workable. At each stage of the game, they simply had to choose between two alternative actions, with one sequence of actions being the subgame perfect Nash equilibrium path through the game tree. Therefore, we believe that we have provided an ideal environment for Maskin's mechanism to work. However, if the participants in our experiment do not exhibit equilibrium play in the majority of cases, we regard this as evidence in favor of the bounded rationality hypothesis.

Some other studies have conducted experimental tests of the holdup model: Hackett (1993, 1994), Olcina (2000), Königstein (2001), Sonnemans et al. (2001), Sloof et al. (2004, 2006, 2007) Bruttel and Eisenkopf (2009), Hoppe and Schmitz (2011) and Erlei and Siemer (2012). Most of these contributions largely confirm the existence of an underinvestment problem and analyze additional aspects of the holdup problem. Yet none of these papers refers to Maskin's mechanism.

Two other papers are more closely related to our study. Aghion et al. (2014) conduct an experimental test on the reliability of the Moore-Repullo mechanism which provided the basis for Maskin's mechanism. They find that the mechanism does not reliably induce truth telling by the players and that deviations from subgame perfect behavior increase if a small amount of uncertainty is introduced. Fehr et al. (2014) is even closer related to our model. The authors test another simplified variation of the mechanism discussed in Maskin (2002). They find that the mechanism fails to increase the players' profits. Fehr et al.'s paper differs, however, in two respects: (a) their simplification of Maskin's mechanism differs from ours substantially. In particular, they analyze a holdup problem with one-sided specific investments and the buyers' message space consists of eleven feasible values. (b) In their effort to explain the failure of the mechanism they emphasize reciprocity. In contrast, in our experiment buyers and sellers have to make an investment decision and our basic explanation of the actual behavior of the participants is based on

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<sup>3</sup> The experimental evidence regarding this reference point approach is mixed (cf. Fehr, Hart and Zehnder (2009, 2011) and Erlei and Reinhold (2011)).

bounded rationality. Since we get similar experimental results, we regard their work as complementary to our study. Finally, we have conducted a second treatment in order to assess whether another institutional safeguard, vertical integration, provides better outcomes.

Our paper is organized as follows. In section 2 we describe the structure of the experimental game, its equilibrium and the experimental procedures. In section 3 we present behavioral predictions. The main results of our experiment are described in section 4. Because the experimental behavior substantially deviates from equilibrium play, we attempt to reconstruct participants' behavior by applying the logit agent quantal response equilibrium to our experimental games in section 5. In section 6 we discuss our findings. Finally we present some conclusions and some perspectives for future research.

## 2 Experimental design

### *2.1 Experimental game*

Motivated by the question of whether the Maskin mechanism can solve the holdup problem, this paper compares its effectiveness with the performance of a much simpler but inefficient alternative: vertical integration. To answer this research question, we implemented two treatments, the Maskin mechanism treatment (MM treatment) and the vertical integration treatment (VI treatment).

The holdup problem considered in this paper consists of the trade relationship between a buyer and a seller. Both parties can simultaneously conduct cooperative specific investments. If the seller decides to invest, he has to bear a cost of  $s = 30$  and increases the buyer's valuation of the product from  $v = 50$  to  $v = 100$ . Accordingly, the overall surplus increases by 20 monetary units ("tokens"). The buyer's costs of investment amount to  $b = 15$  tokens. By investing the buyer decreases the seller's production costs from  $c = 30$  to  $c = 10$ , meaning that the overall surplus increases by 5 tokens. We assume that it is impossible to write a complete contingent contract before conducting the investments and that investment decisions are unverifiable to third parties. Consequently, we have an ordinary holdup problem.

#### *The Maskin mechanism treatment*

The game we have designed for our economic experiment is a simplified version of the mechanism described in Maskin (2002). The main idea behind this mechanism is to solve the holdup problem assuming cooperative investments. In the following we describe our version of the mechanism and its operation according to conventional game theory. It is important to note that the operation of the mechanism depends upon the assumptions of perfect rationality and strictly selfish preferences.

The basic structure of the MM consists of two players, the seller and the buyer, and four stages of play:

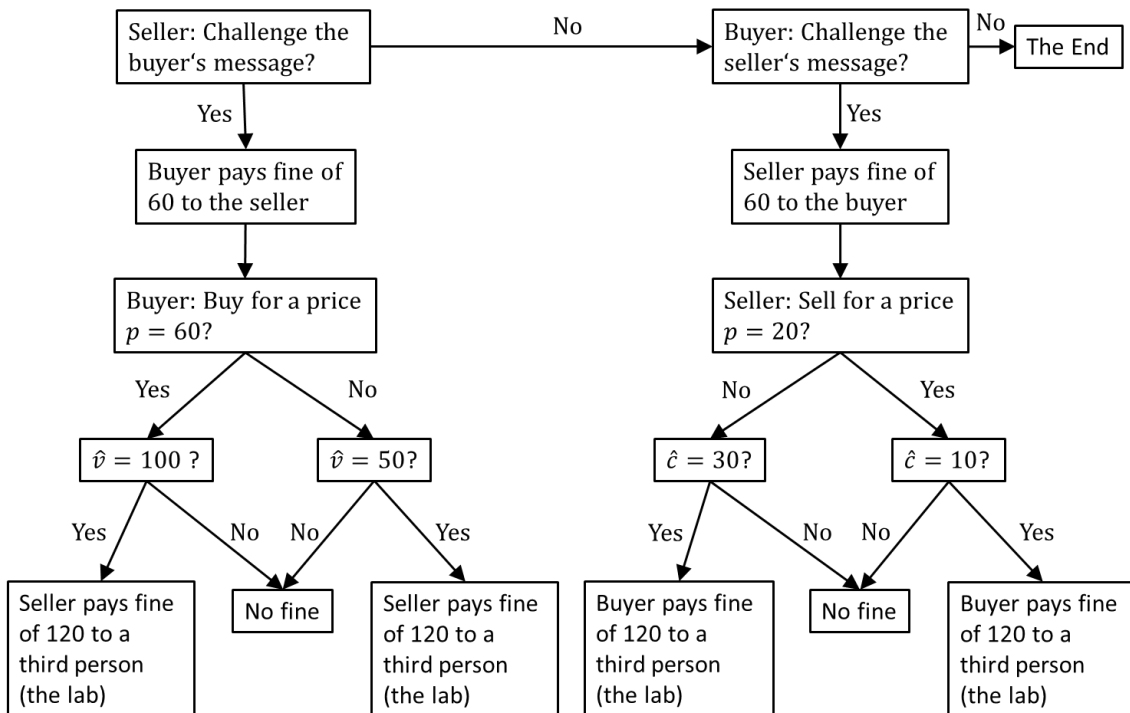
**Table 1: Structure of the Maskin mechanism game**

Stage	Actions
Stage 1:	Simultaneous investment decisions by the buyer and the seller
Stage 2:	The buyer reports his value and the seller reports his cost (simultaneously)
Stage 3:	a) The seller decides whether to challenge the buyers report b) Only if the seller decides not to challenge, the buyer has the opportunity to challenge the sellers report
Stage 4:	If any party has challenged the other party's report, then the challenged party must decide whether to trade according to a prespecified price

In stage 1 both players have to make their investment decision as described above. Since the buyer's investment costs  $b$  are below the induced reduction of the seller's production costs  $c$  and the seller's investment costs are below the induced increase of the buyer's product value, both investments are efficient from a social perspective.

In stage 2 both players send messages to one another. In the buyer's message, he reports his value of the product  $\hat{v} \in \{50, 100\}$ . The buyer may not report the true valuation of the product so that  $v \neq \hat{v}$ . Likewise, the seller reports his costs  $\hat{c} \in \{10, 30\}$ . Again, the seller does not need to report his true costs; hence it is possible that  $c \neq \hat{c}$ . By sending their messages both players unavoidably make an indirect claim regarding one another's investment decision as the buyer's product value can only be 100 if the seller has invested and the seller's production costs will be 10 if and only if the buyer has invested.

As the structure of actions in stages 3 and 4 is quite complex, we have depicted its main elements in Figure 1.

**Figure 1: Sequence of actions in stages 3 and 4**

In stage 3 the seller has the opportunity to challenge the buyer's report, i.e. he may claim that the buyer's message is not true. If he does, the buyer must immediately pay a fine of 60 tokens to the seller. Only if the seller does not challenge the buyers report, the buyer gets the opportunity to challenge the seller's report. Again, if the buyer makes a challenge, the seller has to pay a fine of 60 tokens to the buyer.

If neither player decides to challenge the other party's report, the price of the product being traded between the seller and the buyer is determined to  $p = \hat{v} + \hat{c} - 45$ . Thus, in the case of no challenge, the profits are given by

$$\pi_S = 100 + p - c - s = 100 + \hat{v} + (\hat{c} - c) - s - 45 \quad \text{for the seller and}$$

$$\pi_B = 100 + v - p - b = 100 + (v - \hat{v}) - \hat{c} - b + 45 \quad \text{for the buyer.}^4$$

Stage 4 will only be reached if any player has challenged the other player's report. In this case the challenged player has to decide whether he wants to trade at a prespecified price. This trading decision serves to reveal the true amount of either the buyer's product value or the sellers cost.

If the seller has challenged the buyer's message, the buyer may trade at a price of  $50 < p = 60 < 100$  or he may not trade at all. If  $v = 100$ , the buyer can earn 40 tokens by choosing to trade. If the player is perfectly rational and has purely selfish preferences, he would decide not to forgo this amount of money. Yet if  $v = 50$ , trading will cause a loss of 10 tokens so that a rational and selfish buyer will choose not to trade. If one assumes that players are rational and selfish, the decision of whether to trade reveals the true value of the product. In this sense we define the "revealed buyer's value" ( $v_{rev}$ ) to be.

$$v_{rev} = \begin{cases} 100 & \text{if the buyer trades} \\ 50 & \text{if the buyer does not trade} \end{cases}$$

If the buyer's revealed value is identical to his reported value, then the buyer's message is considered as being true and the seller's challenge of the buyer's message is regarded as inappropriate; hence the seller has to pay a fine of 120 tokens. Yet this fine is not paid to the buyer but to a third party (in our experiment, to the experimental investigator by reducing the seller's profits). If, in contrast, the buyer's revealed value is not the same as his reported value, then the challenge is regarded as appropriate and the seller does not have to pay any fine at all.

If the buyer has challenged the seller's message, the seller has to make a trading decision. He can sell the product at a price of  $10 < p = 20 < 30$  or he can abstain from trading. If the true costs were 10, then a perfectly rational and selfish seller would decide to trade. In contrast, if the true costs were 30, the seller would prefer not to trade. Again, if we assume that all players are rational and selfish, the trading decision can be regarded as a revelation of the seller's true costs. Accordingly, we define the "revealed costs"  $c_{rev}$  as

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<sup>4</sup> Note that we paid an additional amount of 100 to both players in each period because we wished to avoid participants taking losses.

$$c_{rev} = \begin{cases} 10 & \text{if the seller trades} \\ 30 & \text{if he does not trade} \end{cases}$$

Again, if the seller's revealed costs are the same as his reported costs, the seller's message is considered to be true and the buyer's challenge is regarded as inappropriate and the buyer has to pay a fine of 120 tokens (to the experimental investigator). If, in contrast, the seller's revealed costs are not the same as his reported costs, the challenge is regarded as appropriate and the buyer does not have to pay any fine at all.

#### *The equilibrium of the Maskin mechanism game*

To understand the nature of this mechanism, we describe the subgame perfect Nash equilibrium beginning with the last stage and assuming that all players are perfectly rational and purely selfish.

We have already shown that rational and selfish buyers will trade if and only if the products value is 100. In behaving this way, the buyer reveals his true product valuation. In the same way the seller reveals his true costs. Consequently, the challenging party will have to pay a fine of 120 if the challenged party's message was true. Since this fine exceeds the amount of money the challenged party has to pay to the challenging player (60 tokens), the decision to challenge induces a severe loss when the other party has sent a true message. If, in contrast, the challenged party reveals that he has previously sent a false message, the challenger is rewarded for his decision to challenge. Therefore, buyers and sellers will challenge the other transaction partner in stage 3 if and only if the message was false.

In stage 2 both players anticipate that false messages will be challenged and true messages will not. Because the challenged party has to pay a comparatively large fine, it does not pay to send a false message. Accordingly, both players will send true messages.

Anticipating that both players will send true messages ( $v = \hat{v}$  and  $c = \hat{c}$ ) and no player will challenge the other player's message, players' profit functions can be rewritten as follows:

$$\pi_S = 100 + v(s) - s - 45$$

and

$$\pi_B = 100 + 45 - c(b) - b.$$

Because  $v(30) - 30 = 70 > 50 = v(0) - 0$ , the sellers prefer to invest. In the same way buyers prefer to invest because  $-c(15) - 15 = -25 > -30 = -c(0) - 0$ . Consequently, in equilibrium both players will invest send true messages, neither player will challenge the other party's message and total surplus is maximized. The equilibrium profits are  $\pi_S^* = 125$  and  $\pi_B^* = 120$ .

#### *The vertical integration treatment*

In our second treatment we conducted an experimental game with a much simpler structure but an inefficient equilibrium. This treatment is very similar in spirit to the

initial approaches of property rights theory (Grossman and Hart 1986; Hart and Moore 1990) and to transaction cost economics (Williamson 1985).

The game consists of two stages. In stage 1 both players simultaneously make a takeover bid  $p_B, p_S \in [0, 0.1, 0.2, \dots, 99.9, 100]$  for the other player's firm. The subject making the higher offer buys the other player's firm for a price equal to his own bid. In the event that both players make the same bid the winner of this auction is determined randomly.

In stage 2 the owner of the firm decides whether to invest. The subject having sold his firm in stage 1 has no opportunity to act in stage 2. The investments of both players have exactly the same consequences as in the MM treatment, i.e. the seller's investment  $s = 30$  increases the product value from  $v = 50$  to  $v = 100$  and the buyer's investment  $b = 15$  decreases production costs from  $c = 30$  to  $c = 10$ . Recall that buyers can only make investment  $b$  and that sellers can only make investment  $s$ . The player's profit functions are given by

$$\pi_S = \begin{cases} 100 + v(s) - 30 - s - p_{takeover} & \text{in the case of seller ownership} \\ 100 + p_{takeover} & \text{in the case of buyer ownership} \end{cases}$$

$$\pi_B = \begin{cases} 100 + 50 - c(b) - b - p_{takeover} & \text{in the case of buyer ownership} \\ 100 + p_{takeover} & \text{in the case of seller ownership} \end{cases}$$

In equilibrium both types of players will invest if they own the firm because the increase in value (decrease in production cost) is larger than the corresponding investment costs. As the seller's investment increases total surplus by more (20) than the buyer's investment increases surplus (5), seller integration is more efficient than buyer integration. This has an impact on equilibrium behavior in stage 1: As the seller values the firm more than the buyer, his equilibrium bid is higher than the buyer's equilibrium bid. It shows, however, that the auction game in stage 1 has multiple equilibria which are characterized by  $12.5 \leq p_B \leq 19.9$  and  $p_S = p_B + 0.1$ . The correspondent equilibrium profits are given by  $\pi_S = 140 - p_S$  and  $\pi_B = 100 + p_S$ . Because only one player has the opportunity to invest, total equilibrium profits in the VI treatment are lower than those in the MM treatment. In other words, vertical integration is only a second-best solution to the holdup problem in our experimental setting. However, in contrast to the mechanism in the MM treatment, vertical integration is a simple solution which may be more effective if subjects are only boundedly rational.

## 2.2 Experimental procedures

In the MM-treatment 120 subjects participated in six sessions and in the VI-treatment, 40 subjects participated in two sessions. The participants were graduate and undergraduate students at Clausthal University of Technology from a wide variety of programs including Business Administration. In total, 160 subjects participated in two treatments. The computerized experiment was programmed and conducted using zTree 3.2.12 (MM-Treatment) and zTree 3.3.11 (VI-Treatment) software (Fischbacher 2007). In both treatments, the roles of the participants were fixed in a perfect stranger design. Half of the participants were assigned to be buyers and the others were sellers. No subject was



allowed to participate in more than one session. The exchange rate in both treatments was 1 € for 65 tokens. All interactions in the lab were anonymous.

In the MM treatment, a session required between 80 and 85 minutes. In addition to the experiment, this time included the reading time for the written instructions, completing the questionnaire and two practice periods. The announced time was 120 minutes. Subjects earned on average 17.02 € in 10 periods of play, including the show-up fee of 3 €.

In the VI-Treatment, a session lasted between 45 and 50 minutes, again including reading time, completion of the questionnaire and two practice periods. The announced time was 120 minutes. Subjects earned on average 20.74 € in a total of 10 rounds of play, including the show-up fee of 3 €.

To ensure non-negative payoffs, in addition to the profits made in experiment, all participants received 100 tokens at the beginning of each period.

### 3 Behavioral Predictions

Since it is our objective to test the practicability of Maskin's mechanism, our behavioral predictions are derived from the theoretical equilibrium.

*Maskin's Mechanism (MM).* In the fourth stage the buyers or the sellers make the trading decision, if they were previously challenged. Corresponding to the equilibrium, participants will trade (i.e., accept the price of 60 or 20) if and only if the buyer's true value during the seller challenge is  $v = 100$  or the seller's true cost during the buyer challenge is  $c = 10$ . Thus trading decisions are predicted to be the result of the investment decisions from stage 1. Table 1 displays the values and costs for a given investment decision.

**Table 1: Cost and values by varying investment**

	investment	Seller's cost	Buyer's value
Seller's investment	0	-	50
	30	-	100
Buyer's investment	0	30	-
	15	10	-

**Prediction 1.** *The challenged players will trade if either  $c = 10$  or  $v = 100$ .*

In the third stage participants have the opportunity to make a challenge. In equilibrium, challenges will only occur if the investments do not match the messages. Otherwise the challenging party will face with a net fine payment amounting to  $60 - 2 \cdot 60 = -60$ .

**Prediction 2.** *A challenge only occurs if  $c \neq \hat{c}$  or  $v \neq \hat{v}$ .*

In stage 2 buyers and sellers simultaneously send messages regarding their own costs or values, respectively. Due to the perfect anticipation of the behavior in later stages, players

understand that sending a false signal induces a challenge by the other player. Because this leads to the payments of a large fine (60), which is higher than any potential profits due to lying, all players will send true messages in equilibrium.

**Prediction 3.** *Sellers will report their true costs  $\hat{c} = c$  and buyers will report their true values, i.e.,  $\hat{v} = v$ .*

In the first stage sellers and buyers simultaneously decide whether to invest. Realizing that costs and values will be reported correctly and there will be no challenges, the price formula ( $p = \hat{v} + \hat{c} - 45 = v + c - 45$ ) ensures that investing is profitable for both players.

**Prediction 4.** *Sellers and Buyer will invest, i.e.,  $s = 30$  and  $b = 15$ .*

*Vertical Integration (VI).* In the VI-treatment, investment decisions occur during the second stage. At this point in time, the two firms have already merged. Thus, the owner's payoff is no longer dependent on the other player's behavior so that his investment decision is no longer influenced by strategic reasoning. Consequently, the firm owner will make an efficient investment decision:

**Prediction 5a.** *In the VI treatment the owner of the firm will invest efficiently, i.e.,  $b = 15$  or  $s = 30$ .*

In stage 1 buyers and sellers compete for ownership. The participants offer takeover bids for one another's firms. The agent with the larger offer "wins" the auction, pays his offer to the other player and becomes the sole owner of the integrated firm. Because the seller's investment is more productive, his valuation of the firm exceeds that of the buyer. Consequently, the seller will outbid the buyer. Due to the existence of multiple equilibria, we obtain:

**Prediction 5b.** *The auction will lead to seller integration. The equilibrium takeover bids will be  $12.5 \leq p_B \leq 19.9$  and  $p_S = p_B + 0.1$ .*

The mechanism is designed to ensure efficient behavior that solves the holdup problem. In our experiment, vertical integration can only partly solve the holdup problem because only one of the parties can make an investment.

**Prediction 6.** *Profits in the MM-treatment will be larger than those in the VI-treatment; hence  $\pi_S^{MD} + \pi_B^{MD} > \pi_S^{VI} + \pi_B^{VI}$ .*

Prediction 6 is at the core of this paper as it refers to the main question of whether Maskin's mechanism can be trusted to work reliably in practice.

## 4 Results

In this section we present the experimental results of both treatments.

**Result 1.** *Prediction 1 is rejected: in a significant number of cases, buyers trade despite that their product value is only 50 or sellers trade despite that their production costs are 30.*

Table 2 reports the trading decisions in stage 4. In nearly 40% of the observations, buyers deviate from the predicted equilibrium behavior. For the sellers, precisely 37.5% of the decisions are not in accordance with SPNE. As a consequence, in the early stages of the game, players cannot rely on subsequent equilibrium behavior.<sup>5</sup>

Table 2: Trade decisions in stage 4		
	MM	
	Buyer challenges	Seller challenges
Equilibrium behavior	111	130
Disequilibrium behavior	72	78
Percentage of equilibrium decisions	60.7 %	62.5%

**Result 2.** *Prediction 2 is rejected: there is a non-negligible number of observations in which players challenge the other party while the message was true or players do not challenge the other player despite the message being false.*

According to our equilibrium prediction, players only challenge the other subject's message if the message is false. Table 3 shows that the experimental behavior frequently deviates from equilibrium predictions. Buyers do not make equilibrium decisions in more than one-third of cases, while the corresponding figure for sellers is 31.2 percent.<sup>6</sup>

Table 3: Decisions to challenge in stage 3		
	MM	
	Buyers' decisions to challenge	Sellers' decisions to challenge
Equilibrium choices	243	413
Disequilibrium choices	149	187
Percentage of equilibrium choices	61.9 %	68.8%

**Result 3.** *Prediction 3 is rejected: on average, one-third of the messages are false.*

<sup>5</sup> In a logit regression we attempted to identify variables that might explain experimental behavior in stage 4. However, none of the explanatory variables (prior behavior in the same period and some other variables) were significant at conventional levels.

<sup>6</sup> We conducted a logit regression revealing a significant impact of one's own investment and the truthfulness of the other player's message on the rationality of the sellers' decision to challenge. Yet this result does not hold for buyers' decisions of whether to challenge.

Table 4 indicates that in nearly 30 percent of cases the buyers sent false messages concerning their product valuation. In more than 35% of the cases sellers do not report their true costs.<sup>7</sup>

**Table 4: Quantities of messages in accordance with investment decisions**

	MM	
	Buyers' messages	Sellers' messages
True	437	387
False	163	213
Percentage of true messages	72.8 %	64.5%

**Result 4.** *Prediction 4 is rejected: in 38.9 percent of the observations, players did not invest.*

According to equilibrium predictions the mechanism is able to solve the holdup problem perfectly such that buyers ( $b = 15$ ) and sellers ( $s = 30$ ) will always invest. Yet table 5 shows that this is far from being true. Buyers did not invest in 40.7 percent of cases and, sellers did not invest in 37.2 percent of cases. Consequently, the mechanism provides no behaviorally workable first-best solution to the holdup problem.

**Table 5: Quantities of investment decisions in the MM treatment**

	MM	
	Buyers	Sellers
Efficient investment ( $s = 30$ or $b = 15$ )	356	377
No investment ( $s = 0$ or $b = 0$ )	244	223
Percentage of efficient investments	59.3 %	62.8%

Having presented all results concerning participants' behavior in the MM treatment, it remains to be shown whether theory performs better in the VI treatment. Let us begin the description of behavior in stage 2 of the treatment, the investment decision.

**Result 5a.** *Prediction 5a is rejected: in 15 percent of VI treatment cases, players did not invest.*

According to equilibrium predictions both players will always invest once they own the firm. Table 6 indicates that this is not the case as there is a non-negligible number of cases in which the owner of the firm makes no investment. The percentage of non-investing

<sup>7</sup> In logit regressions, we found that the investment behavior of the other party has a significant impact on the truthfulness of messages.

buyers and sellers is approximately 15 percent which is far less than in the MM treatment but still too high to claim that firm owners always invest.

**Table 6: Quantities of investment decisions in the VI-treatment**

	VI	
	Buyers	Sellers
Efficient investment ( $s = 30$ or $b = 15$ )	85	85
No investment ( $s = 0$ or $b = 0$ )	16	14
Percentage of efficient investment	84.16 %	85.86 %

**Result 5b.** *Prediction 5b is rejected: in stage 1, buyers win the auction in the majority of cases. In addition takeover bids are well above the predicted level ( $12.5 \leq p_i \leq 20$ ).*

According to equilibrium predictions, sellers will always win the auction in stage 1 because their investments are more productive than those of the buyers. Table 7 reports that in 101 out of 200 cases buyers win the auction and become the firm owners. In contrast to the MM treatment, we observe some learning in the VI treatment. In the final three periods of play, sellers win the takeover auction in approximately 62 percent of the cases. Yet, even in these periods, there are clearly too many buyer integrations to confirm the hypothesis that sellers will always become firm owners.

**Table 7: Takeover bids and ownership structures**

	VI	
	Buyers	Sellers
Mean takeover bid	28.60	25.24
Number of auction wins	101	99
Percentage of auction wins	50.5 %	49.5 %

Thus far we have shown that the participants' behavior deviates substantially from equilibrium predictions. It remains to be shown, however, whether the use of the mechanism improves economic performance. We employ two benchmarks to assess the efficiency of the participants' behavior in both treatments. The first is the first-best solution and yields the total profit of 245. The Maskin mechanism was originally designed to achieve this result. The second benchmark, the zero investment baseline, consists of both players' payoffs in the case that neither of them invests and neither challenges the

other. Here the sum of total profits equals 220. In essence, this benchmark serves as the case in which there is no institutional arrangement to solve the holdup problem.

**Result 6.** *Prediction 6 is rejected: total profits in the VI treatment are significantly higher than in the MM treatment.*

Table 8 shows that the profits in the VI treatment are between the two benchmark cases in the last three periods. In the previous periods, and even in the last three periods, the buyers' bids are above equilibrium offer. As we observe some non-investment by firm owners, total surplus is slightly below the equilibrium of the VI treatment. As an instrument to alleviate the holdup problem, vertical integration may best be regarded as an imperfect but workable solution.

In contrast, the Maskin mechanism completely fails to solve the holdup problem. The profits of both buyers and sellers are well below the zero investment benchmark. Thus, implementing the mechanism does not improve but instead impairs economic performance. Furthermore, the subgame perfect equilibrium path was only realized in 63 (out of 600) interactions.

**Table 8: Mean Profits**

	Buyer		Seller	
	Total	Last three periods	Total	Last three periods
MM treatment	98.03	96.97	84.24	83.28
VI treatment	107.55	115.79	123.08	117.04
First-best equilibrium	120		125	
Zero investment case (no institutional arrangement)	115		105	

Summarizing the results of our experiment, (1) the implementation of the Maskin mechanism leads to worse payoffs than ignoring the holdup problem entirely, and (2) without exception, all predictions based on equilibrium theory must be rejected. Consequently, the question arises whether there is a better approach to explain the behavior of subjects in our experiment. In the next section we attempt to show that the logit agent quantal response equilibrium (LAQRE) is able to reconstruct the basic features of the behavior and economic performance in our experiment.

## 5 Logit agent quantal response equilibrium

We began our economic experiment under the presumption that Maskin's mechanism is far too complicated to be employed in practice. Due to the successful use of the logit quantal response equilibrium as an alternative to the Nash equilibrium, it is currently

widely accepted as a static benchmark (cf Camerer et al. 2004); hence its application needs no further justification.

In logit quantal response equilibria (LQRE) subjects do not perfectly optimize but choose each feasible strategy with a strictly positive probability. The probability  $pr_{ki}$  of subject  $k$  choosing a particular strategy  $a_i$  increases in its expected utility and is described by the following logit choice function:

$$pr_{ki} = \frac{e^{\frac{EU_{ki}}{\mu}}}{\sum_j e^{\frac{EU_{kj}}{\mu}}}$$

Subject  $k$ 's expected utility, in turn, depends on his expectations of the other players' probabilities of choosing their feasible strategies  $\sigma_{ky}$ :  $EU_{ki} = f(\sigma_{11}, \sigma_{12}, \dots, \sigma_{ky}, \dots, \sigma_{nm})$  for all players and all strategies. In addition to the logit choice rule LQRE includes a consistency requirement:  $\sigma_{ky} = pr_{ky}$ . In other words, players' expectations of other players' behavior are correct (in a probabilistic sense).

The parameter  $\mu$  in the logit choice function measures the players' degree of rationality. The smaller the parameter value, the higher is the degree of rationality assumed. If  $\mu$  approaches zero, LQRE coincides with the subgame perfect Nash equilibrium. If, in contrast,  $\mu$  approaches infinity, each feasible strategy is chosen with equal probability. The additional parameter provides an additional degree of freedom. Typically the parameter is estimated for each game separately by using maximum likelihood techniques.

The concept of logit agent quantal response equilibrium (LAQRE) extends LQRE by accounting for the dynamic structure of the game. This extension is achieved by using the agent normal form of the game and calculating its LQRE. In the following we apply LAQRE to the experimental games in the two treatments. Our maximum likelihood estimations of the rationality parameter are  $\mu = 42.17$  for the game played in the MM treatment and  $\mu = 27.54$  for the VI treatment.

### 5.1. The LAQRE of the Maskin mechanism game

The LAQRE probabilities for the trading decision in stage 4 are presented in table 9. Clearly, the LAQRE probabilities are much closer to the corresponding empirical values than the predictions of the subgame perfect Nash equilibrium (SPNE). This phenomenon is particularly the case for the buyers' decisions to trade during seller challenges.

**Table 9: Probabilities of trading at stage 4**

	Empirical percentages	LAQRE probabilities (%)	SPNE (%)
Buyer challenges (i.e. sellers decide whether to trade)			
$c = 10$	71.9	<b>55.9</b>	100
$c = 30$	65.5	<b>44.1</b>	0

Seller challenges (i.e., buyers decide whether to trade)			
v = 50	44.4	<b>44.1</b>	0
v = 100	68.8	<b>72.1</b>	100

In the case of buyer challenges LAQRE still clearly outperforms SPNE but the distance between the LAQRE probabilities and the empirical values is also substantial. When  $c = 30$  the distance is 21.4 percent. It is important to understand that Maskin's mechanism critically depends on a behavior in accordance with the SPNE in stage 4 because only this clear-cut equilibrium behavior can serve as a reliable revelation of true costs and values, respectively. Deviations from standard Nash equilibrium lead to modified incentives at earlier stages of the game and thereby destroy incentives to invest in stage 1.

In stage 3 the seller (and subsequently the buyer if the seller does not challenge) has to decide whether to challenge the other player's message. Since Maskin's mechanism crucially depends on the identity of true costs and reported costs and on the identity of true values and reported values, we have to distinguish four constellations of true costs and values and four constellations of reported costs and values. In addition, we have to distinguish between buyers' (BC) and sellers' decisions to challenge (SC). Table 10 provides an overview of the empirical data, the LAQRE and the SPNE for all 32 constellations. The upper line in each cell provides the value of the SPNE, followed by the LAQRE and the empirical relative frequency. The empirical values in square brackets are based on a subsample of fewer than or exactly 5 cases.

To quantitatively compare the predictive power of SPNE and LAQRE, we calculated the mean absolute deviation (MAD) between the theoretical and empirical probabilities. Taking into account all 32 cells we obtain  $MAD_{LAQRE} = 0,1242$  and  $MAD_{SPNE} = 0,3394$ . Ignoring the cells in which the number of empirical cases is smaller than five, we obtain  $MAD_{LAQRE} = 0.1205$  and  $MAD_{SPNE} = 0.3351$ . Obviously, LAQRE outperforms SPNE. Greater deviations in a few cells notwithstanding, LAQRE can generally reconstruct the subjects' challenge behavior in our experiment.



**Table 10: The decision of whether to challenge the other party's message**

		$c = 10; v = 100$	$c = 30; v = 100$	$c = 10; v = 50$	$c = 30; v = 50$
SPNE SC	$\hat{c} = 10; \hat{v} = 100$	0	0	1	1
LAQRE SC		0,2539	0,2798	0,3513	0,4138
Data SC		0,0841	0,4444	0,2941	0,6667
SPNE BC	$\hat{c} = 10; \hat{v} = 100$	0	1	0	1
LAQRE BC		0,5156	0,5435	0,6423	0,6979
Data BC		0,3571	0,8	0,5417	[0,5]
SPNE SC	$\hat{c} = 30; \hat{v} = 100$	0	0	1	1
LAQRE SC		0,1748	0,1947	0,2520	0,3052
Data SC		0,1667	0,1791	0,1765	0,3636
SPNE BC	$\hat{c} = 30; \hat{v} = 100$	1	0	1	0
LAQRE BC		0,7053	0,5776	0,8015	0,7263
Data BC		0,6615	0,3818	0,3571	0,7143
SPNE SC	$\hat{c} = 10; \hat{v} = 50$	1	1	0	0
LAQRE SC		0,7965	0,8171	0,5588	0,6228
Data SC		0,6552	0,6667	0,4074	0,4242
SPNE BC	$\hat{c} = 10; \hat{v} = 50$	0	1	0	1
LAQRE BC		0,2454	0,2668	0,3543	0,4138
Data BC		0,5	[0,75]	0,2813	0,4737
SPNE SC	$\hat{c} = 30; \hat{v} = 50$	1	1	0	0
LAQRE SC		0,7089	0,7355	0,4408	0,5068
Data SC		0,6667	0,8718	0,5814	0,3696
SPNE BC	$\hat{c} = 30; \hat{v} = 50$	1	0	1	0
LAQRE BC		0,4224	0,2947	0,5523	0,4477
Data BC		0,8	0,5	0,7778	0,3448

Let us now turn to the contents of the messages. At this stage of the game we can distinguish four cases: costs and values can be either high or low. Table 11 shows of the probabilities of sending true messages according to SPNE, LAQRE and the empirical data. Once again, LAQRE fits the data much better than SPNE. Taking the mean absolute deviation over all eight cells as a measure of the goodness of fit, LAQRE (MAD = 0.1262) is clearly closer to the empirical data than SPNE (MAD = 0.3235). We find only two cells ( $c = 30, v = 100, \hat{c}$ ; and  $c = 30, v = 50, \hat{c}$ ) in which SPNE is closer to the data.

**Table 11: LAQRE in stage 2 (sending messages)**

		Probabilities of true messages ( $\hat{c} = c$ or $\hat{v} = v$ )			
		$c = 10; v = 100$	$c = 30; v = 100$	$c = 10; v = 50$	$c = 30; v = 50$
SPNE	$\hat{c}$	1	1	1	1
LAQRE		0,5638	0,5051	0,5600	0,4864
Data		0,5939	0,8346	0,5946	0,5938
SPNE	$\hat{v}$	1	1	1	1
LAQRE		0,6753	0,6495	0,4655	0,4636
Data		0,8079	0,5984	0,6554	0,6964

Table 12 shows the LAQRE probabilities of investment and players' expected profits in comparison to SPNE and the participants' behavior in our experiment. Again, LAQRE is

much closer to the empirical data. Yet the difference between the relative frequency of buyers' investments and the investment probabilities according to LAQRE remains rather large. Most important, LAQRE can explain the surprisingly low value of mean profits in our experiment. LAQRE explains deviations from equilibrium behavior at all stages of the experimental game and thereby explains the occurrence of inefficient challenges and the inefficient payment of fines. Consequently, expected profits in the LAQRE are well below 100. In other words: completely ignoring the holdup problem and thereby realizing maximum underinvestment induces larger profits (105/115) than using Maskin's mechanism.

**Table 12: Investment probabilities and expected profits in the LAQRE**

<b>Investment probabilities</b>			
	Data	LAQRE	SPNE
Sellers	0,5933	0.4115	1
Buyers	0,6283	0.4507	1
<b>Expected profits</b>			
	Data	LAQRE	SPNE
Sellers	84,22	85,62	125
Buyers	98,03	84,29	120

We have demonstrated that the LAQRE provides a much better fit to the data than the SPNE. It is unsurprising that the LAQRE, as a generalization of SPNE that has an additional degree of freedom (parameter  $\mu$ ), yields a better fit for the entire game. Yet it is not self-evident that LAQRE outperforms SPNE in all stages of the game which is true for our MM treatment. Furthermore, the LAQRE not only provides a better fit but also inverts the normative evaluation of the Maskin mechanism, and this is perfectly in accordance with the data from our experiment. The Maskin mechanism is simply overly complicated to reliably work with ordinary individuals who are only boundedly rational. Yet mechanism design does not take into account any limits of human rationality and thereby overestimates the efficiency of its solutions.

## *5.2 The LAQRE in the Vertical Integration game*

Stage 2 of the VI treatment consists of a large trivial investment decision by the owner of the firm. He need only understand that his investment costs are lower than the benefit of the investment, and hence it is beneficial to invest. Table 13 shows that the subjects in the VI treatment generally understood this. The average empirical investment probability is approximately 85 percent whereas LAQRE, assuming that  $\mu = 27.54$ , predicts substantially smaller investment probabilities. Consequently, SPNE outperforms LAQRE in stage 2 of this treatment.

**Table 13: Investment probabilities in the VI treatment**

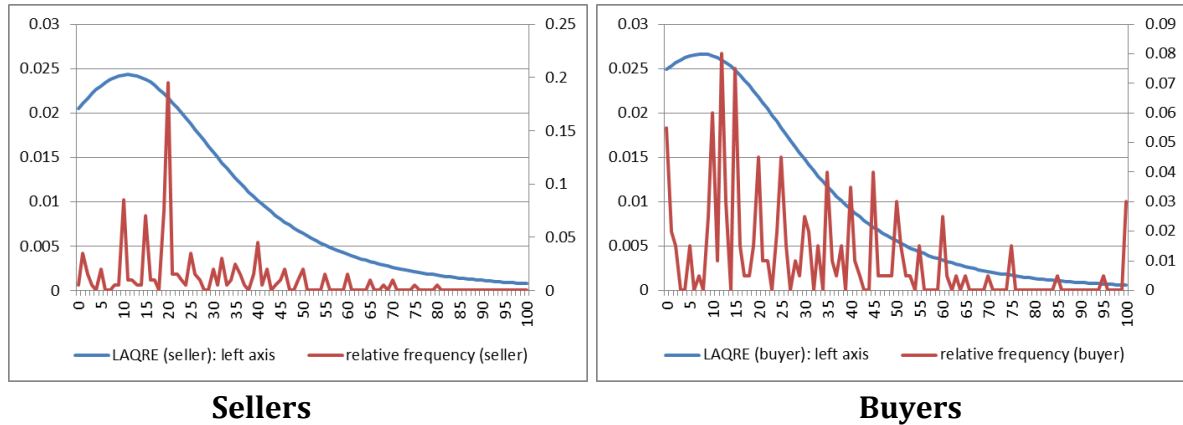
	Data	LAQRE	SPNE
Sellers	0.8586	0.6740	1
Buyers	0.8416	0.5453	1

The ownership of the firm is auctioned in stage 1 of the VI game. Table 14 shows that both buyers and sellers submitted substantially higher bids than predicted by SPNE. By and large, LAQRE captures players' overbidding quite well.

**Table 14: Mean takeover bids**

	Data	LAQRE	SPNE
Sellers	25.235	26.020	$p_{\text{Seller}} = p_{\text{Buyer}} + 0.1$ and
Buyers	28.598	23.864	$12.5 \leq p_{\text{Buyer}} \leq 19.9$

LAQRE not only approximates the means of takeover bids but also provides an approximate estimate of the distribution of bids. Figure 2 shows the relative frequencies of takeover bids and the corresponding LAQRE probabilities. One can see that the shapes of the distributions are similar. Yet LAQRE does not capture the preferred choice of prominent numbers as takeover bids. Obviously, multiples of five are overrepresented in the distribution of takeover bids. Furthermore, the peak of the LAQRE distribution lies left to the peak of takeover bids for buyers and sellers.

**Figure 2: Relative bid frequencies and LAQRE probabilities of takeover bids**

In summary, the LAQRE of the VI game can explain why (a) we observe many cases of buyer integrations and (b) takeover bids are well above the level predicted by SPNE. Yet it underestimates the efficiency of investment decisions in stage 2.

## 6 Discussion

The complementary papers by Aghion et al (2014) and Fehr et al. (2014) refer to social preferences to explain the failure of Maskin's mechanism and the Moore-Repullo mechanism. In particular, they emphasize that reciprocity or preferences for retaliation might explain their participants' behavior. It seems to work well in their experiment. However, it does not work as well for our data.

To show this, we concentrate our discussion on two versions of social preferences: reciprocity and inequity aversion. Reciprocity captures the idea that people desire to punish uncooperative behavior (negative reciprocity) and reward cooperative behavior (positive reciprocity). Inequity aversion (e.g., Fehr and Schmidt 1999), in contrast, extends the utility function by an additional argument: the difference in the players' payoffs. Any increase in the absolute value of payoff differences decreases utility of inequity averse players.

Take the following case: The seller has invested, the buyer has not invested in stage 1 and both players have sent true messages:  $c = \hat{c} = 30$  and  $v = \hat{v} = 100$ . The seller has not challenged the buyer's message and now it is up to the buyer to decide whether to challenge the seller's message. The following cases are possible under these circumstances:

Table 15: Payoffs ( $\pi_S, \pi_B$ )

	Seller sells ( $p = 20$ )	Seller does not sell
Buyer challenge	(0, 240)	(10, 40)
No buyer challenge	(125, 115)	

If the buyer does not challenge the seller's message he gets a payoff of 115, slightly less than the seller (125). If the buyer challenges and the seller sells the buyer realizes a profit of 240 and the seller gets nothing. If the seller does not sell the product after a challenge the seller earns 10 and the buyer gets 40. Let us now analyze the seller's decision of whether to sell the product. What kind of players would choose to sell the product?

Selling the product for  $p = 20$ , i.e., selling below cost (30) decreases the seller's profits, thus selfish players will never sell the product in this special case. What about inequity aversion? The payoff difference in case of selling the product is much higher than in case of not selling. Therefore, inequity averse sellers will suffer an additional disutility if they sell the product under these circumstances. As payoffs are greater and the payoff difference is smaller if the sellers don't sell, inequity averse players will not sell in this buyer challenge.

Then, what about reciprocity? The buyer's decision to challenge despite the seller having sent a true message can hardly be understood as cooperative behavior. Quite the contrary, a common interpretation of this "unjustified" challenge would be that the buyer has behaved uncooperatively and deserves a punishment. Again, reciprocal sellers will not sell the product. In summary, all types of sellers will prefer not to sell to the buyer.

As the buyer cannot expect sellers to sell, why should he challenge the seller's message if this decreases his profits from 115 to 40? One might guess that he wants to act reciprocally by himself. Yet this argument does not work here because the seller has behaved cooperatively in all previous stages: the seller has invested, sent a true message and not challenged the buyer's message. What more could he do? Inequity aversion can also not serve as an explanation for a buyer challenge because payoff differences in a buyer challenge are greater than in the case without a buyer challenge.

In summary, no rational seller type (selfish, inequity averse or reciprocal) will sell the product in our specific case and no rational buyer type will challenge the seller's message. However, in our experiment 50 percent of the buyers have decided in favor of a challenge under these circumstances!

A similar analysis can be made for other cases as well; e.g., if we have equilibrium behavior in the first two stages, meaning  $c = \hat{c} = 10$  and  $v = \hat{v} = 100$ , we find buyer challenges in 29 percent of the cases. Again, social preferences can hardly explain this deviation from equilibrium. Consequently, reciprocity and inequity aversion are unable to reconstruct central characteristics of behavior in our experiment; hence we prefer bounded rationality as an explanatory approach to reconstruct our data.

## 7 Conclusion

Several decades ago institutional economics emerged as an approach emphasizing that bounded rationality should be at the core of the research program (Williamson 1975, 1985). Beginning with the seminal paper by Grossman and Hart (1986), the emphasis shifted to game theoretic models with perfectly rational players. Oliver Hart (1990, 696) claimed that "bounded rationality in the sense that agents have limited cognitive, computational or comprehension skills is not" a crucial component of the theory of institutions. The research program called the "theory of incomplete contracts" emerged and evolved, and many ingenious solutions to the holdup problem were introduced. Subsequently, papers by Maskin and Tirole (1999), Maskin and Moore (1999) and Maskin (2002) raised doubts regarding the foundations of this program by introducing a mechanism ensuring efficient equilibria.

Maskin (2002) emphasizes that he does not believe that we should ignore the results of this strand of literature which he seems to consider valuable. Furthermore, he supposes that bounded rationality could be a potentially fruitful explanation for incompleteness. We agree with Maskin that the theory of incomplete contracts retains substantial heuristic value. Furthermore, the results of our experiment strongly confirm Maskin's second assessment (referring to bounded rationality) and show that implementing the proposed mechanism may lead to disastrous economic consequences. Traditional game theoretic equilibrium analysis cannot account for our experimental data. However, the application of LAQRE, which explicitly accounts for players mistakes, can reconstruct the important results of our experiment: LAQRE outperforms SPNE as a predictor of behavior at all stages of the MM treatment.

We regard our findings as evidence for the unfeasibility of overly complex institutional arrangements. In our case the use of the complex mechanism does not improve performance, rather it worsens it: participants' payoffs are even smaller than in an institutional setting that completely ignores the holdup problem! In contrast, the simple but inefficient solution of vertical integration leads to a significant improvement in economic performance.

As a first consequence, we submit that – in stark contrast to Hart (1990) – bounded rationality is a crucial component of the theory of the firm and that of institutions in general. In some respects Williamson (1985) provided a deeper and better understanding than the current theory of incomplete contracts.

The second conclusion we wish to draw is that solutions to incentive problems must be simple to be workable with human players. Our final conclusion is that most solutions to the different versions of the holdup problem should be reassessed in light of our findings. By this we mean that the complexity of institutional arrangements must be taken into account and it is difficult to imagine that first-best solutions exist. Some important steps have already been taken in this direction: the contributions of Hoppe and Schmitz (2011), (2013a) and (2013b) provide particularly valuable insights.

Although LAQRE clearly outperforms SPNE, there remains a substantial potential for further improvements in predicting and explaining subjects behavior in contract theoretic experiments. First, it seems promising to rely more heavily on learning models. Second, a combination of bounded rationality and social preferences may be able to fill in some of the gaps that remain in our analysis of this experiment. Finally, we may be able to deepen our understanding by using tools other than equilibrium analysis, e.g. agent-based models of organizations might serve as a useful complement to (behavioral and traditional) game theory. We eagerly anticipate works pursuing these directions.

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